Evaluating the construction of prominent scenarios for a low-carbon European power system in 2050

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***Abstract*—Given the stringent climate constraints the European Union has put forward for the power sector, the European energy system will have to change drastically. Although presenting a great number of challenges, the necessary transformation of our energy system also presents us with the opportunity to move towards a more sustainable society. This means balancing economic and social development with environmental protection, known as the *triple bottom line*. This work will focus on scenarios for the future electric energy system with high levels of renewable energy to realise this transformation. To adequately evaluate the challenges this poses the modelling of the energy system has to be sufficiently detailed. The last few years a number of high-level studies have been published exploring possible pathways for the evolution of national and regional energy systems towards a low-carbon 2050 energy system. Four prominent studies have been examined in detail as to how they model the operational aspects of the energy system, namely: *Energy Roadmap 2050* by the European Commission, *Power Choices* by EURELECTRIC, *Roadmap 2050* by the European Climate Foundation and *Battle of the Grids* by Greenpeace. They are compared in terms of how they model supply, demand and the flexibility options of an energy system. A number of opportunities are found for the improvement of the construction of roadmaps for a low-carbon European energy system. The main focus is on the assessment of the technical feasibility of the proposed supply side configurations.**

***Index Terms*—Europe, power system planning, power system modeling, power transmission, environmental factors.**

I. Introduction

In Europe the European Union's ambitious climate policy has driven the Member States for several years to consider the future of their energy system. European Guidelines and Directives already set targets for 2020. Now Europe's view is reaching beyond that, envisaging the 2050 horizon. Limiting the increase in global temperature to 2°C above pre-industrial temperatures with a probability of at least 50% implies halving the global emissions by 2050 [1]. Assuming equal per capita emissions by 2050, this comes down to an 85% emission reduction for developed countries [2]. Hence "the European Council reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990" [3]. The European Commission published 4 roadmaps to outline the European vision, amongst which the *Energy Roadmap 2050* produced by the Directorate-General for Energy [4]. Given the Commission's limited ability to enforce energy policy, the scope of the document is limited to the analysis of a number of illustrative scenarios and the identification of "no regret" options. Yet the direction the Commission chooses to move in is of key importance. Therefore, leading up to the publication of its vision, multiple organisations published their own studies in an attempt to influence European policy. Three of the most prominent of those have been selected to be compared with the *Energy Roadmap 2050* as to how they model the energy system and its evolution towards 2050. Thus four studies will be compared:

1) *Energy Roadmap 2050*; European Commission [ECM]
2) *Power Choices*; EURELECTRIC [EUR] [5]
3) *Roadmap 2050*; European Climate Foundation [ECF] [6]
4) *Battle of the Grids*; Greenpeace [GRE] [7]

The operation of the electricity system has to be modelled in sufficient detail to adequately evaluate the ability of a proposed supply side configuration to deal with high shares of renewable energy sources (RES) in the power supply. Of specific interest for this work is the way in which the different types of operational flexibility of the power system are represented, as these will be key in dealing with the intermittent character of the RES. Five types of operational flexibility can be identified: (1) the flexibility of dispatchable generation, (2) flexibility services from intermittent RES, (3) demand response, (4) power exchange and (5) energy storage [8]. It is important for long-term energy planning models to consider all of these options to allow benefiting from their synergies. E.g. [9] argues that some grid reinforcements can be avoided or delayed via the proper use of energy storage and demand response.

This paper will discuss if and how these types of flexibility are represented in the modelling of the four studies. In addition the studies' main assumptions and additional modelling methodologies for supply and demand are reviewed. Section II will shortly introduce the four studies and their mission statements. Section III discusses the modelling of the supply side and the flexibility from dispatchable and intermittent generation sources. Section IV handles the modelling of the demand side and demand response. Finally Section V deals with the modelling of power system infrastructure (i.e. power transmission and energy storage).

II. 4 prominent studies

A. Energy Roadmap 2050

The *Energy Roadmap 2050* study was drafted by the European Commission's Directorate-General for Energy. Its goal is the identification of "no regret" options in the European energy system through a scenario analysis of an "illustrative

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nature" focusing on the common elements of ways to modernise the energy system. This should allow the development of a long-term European technology-neutral framework. To this end a *Reference scenario* including all policies adopted by March 2010, and a *Current Policy Initiatives* scenario, including more recent policies (e.g. the "Energy Efficiency Plan"), are compared to five decarbonisation scenarios: *High Energy Efficiency*, *Diversified Supply Technologies*, *High Renewable Energy Sources*, *Delayed CCS* and *Low Nuclear*.

B. Power Choices

EURELECTRIC is the association of the electricity industry in Europe representing electricity producers, suppliers, traders and distributors in 32 European countries [10]. The goal of its *Power Choices* study is to define the "optimal portfolio of power generation" and the technological developments needed to reach the GHG reduction target. A *Reference scenario* with a less stringent climate and energy policy is compared to the main *Power Choices scenario*. Four sensitivity analyses are performed: (1) a delay of CCS to 2035, (2) no nuclear phase-out in Belgium nor Germany, (3) a lesser deployment of onshore wind and (4) ETS as the sole driver for investments.

C. Roadmap 2050

The European Climate Foundation promotes climate and energy policies that strongly reduce Europe's GHG emissions and help it play a leading role in the international climate change debate [11]. Its *Roadmap 2050* study aims to assess the technical and economic feasibility of a number of decarbonisation pathways while at least maintaining supply reliability, energy security and economic growth and prosperity. 3 scenarios with a varying share of RES (40%, 60% and 80%) in the electricity production are examined. A 100% renewable scenario is also tested, with import from North Africa.

D. Battle of the Grids

Building on the *Advanced Scenario* of the *energy [r]evolution* study Greenpeace and Energynautics collaborated for a follow-up study. Energynautics is an engineering office located in Germany that handles projects in the area of wind and other RES, specialising in network integration and power markets [12]. The *Battle of the Grids* study assesses the need for extra grid reinforcements and production capacity in a system with a 97% share of RES in the electricity production to ensure that the security of electricity supply is up to current standards. 2 grid reinforcements scenarios are compared. The *Low Grid scenario* allows no import of electricity from North Africa. The *High Grid scenario* does allow such import, but restrains it to 60 GW to limit transmission investments costs.

III. Modelling Supply

This section covers concisely how generation capacity additions are handled by the models before looking at the 2 types of flexibility of the supply side. A first major distinction is the way in which the discussed studies constitute their generation portfolios. These can either be an input or an output of the modelling process, depending on the model the studies use. [ECM] and [EUR] both rely on the PRIMES model, which allows endogenous investment in generation capacity. [ECF] and [GRE] impose a set of generation portfolios. These can, however, be supplemented with back-up generation (BUG).

PRIMES, a partial equilibrium energy system model, simulates a market equilibrium solution for energy supply and demand for the European Union [13]. Given the respective inputs of [ECM] and [EUR] (such as policy or emission reduction targets), PRIMES determines the optimal portfolio by calculating the production capacity needed to balance electricity demand and supply during 11 "typical" time segments of the year. Through the use of (representative) agents on supply and demand side, each maximising their own benefit [14, p.36], the model generates an investment roadmap to an almost carbon neutral power sector by 2050 [5, p. 35].

[ECF] wants its scenarios, with predefined generation mixes, to achieve today's level of reliability (i.e. a loss of load expectation lower than 4 hours/year) [15]. To adapt its scenarios accordingly it considers an economic trade-off between 3 options: (1) additional BUG (open cycle gas turbines priced at €350,000 per MW), (2) inter-regional transmission capacity (€1,000 per MW per km, with the distance being the length between *centres of gravity*, see Section V) and (3) the cost of loss of load (assumed at €50,000 per MWh).

[GRE] evaluates the generation portfolio proposed in the *Advanced Scenario* of Greenpeace's *energy [r]evolution* study. *Energynautics* concludes that the proposed import capacity from North Africa in the *Advanced Scenario* would require unrealistically large quantities of grid reinforcements. Therefore it devises the 2 scenarios mentioned in Section II where import is limited to 60 GW in one scenario and excluded in the other. But even in the scenario where import is allowed, generation capacities are insufficient to meet demand. Hence *Energynautics*' model adds to the generation portfolio with new photovoltaic and wind capacity to cover energy shortage and biomass capacity to provide sufficient balancing power [16]. These capacity additions are significant, amounting to 260 GW of PV and 112 GW of biomass in the *High Grid scenario* and 470 GW of PV, 170 GW of wind and 236 GW of biomass in the *Low Grid scenario* (no import) [17]. This is to be compared with the 498 GW of PV, 497 GW of wind and 100 GW of biomass in the original *Advanced Scenario*.

A. Dispatchable generation

A first source of flexibility in the power system is the ability of dispatchable generation units to alter their output level. This alteration is subject to several constraints, such as a unit's ramping rates or minimal up and down times.

To determine the output of its dispatchable generation while respecting these constraints PRIMES solves a unit commitment-dispatching problem. The model considers more than 250 plant types, grouping the units per country [14].

[ECF] adopts a stochastic optimisation framework for the scheduling of production and reserves. The model looks ahead at the demand profile and corresponding reserve requirements to be met in the following 36 hours. Subsequently it schedules generation (constrained by its dynamic characteristics), storage and use of demand response for the next 24 hours while minimising generation costs and taking into account the stochastic behaviour of the RES production [15].

[GRE] relies on the Power Factory software [18] to calculate the dispatch of generation and solving an optimal power flow. The mismatch between demand and variable RES output is calculated at each node. The model first attempts to meet a shortage of supply with the controllable RES before addressing conventional sources. [GRE] considers coal and nuclear power to be inflexible, modelling them with a flat production profile. Gas power are assumed to be able to respond to fast changes.

It is imperative that the balance between supply and demand is checked on at least an hourly basis throughout the year, especially when considering systems with high shares of RES. The stretches of time where both solar and wind energy output are low will be decisive for the design of the energy system. It also necessary to account for the uncertainty of the output of variable RES. Power system reserves have to be sized appropriately to be able to deal with output levels that deviate from the forecasts. This will have implications on the composition of the generation portfolio.

B. Intermittent generation

The modelling of the output of variable RES is crucial for a model's capability to assess the energy system's ability to address the challenges posed by intermittent generation.

PRIMES uses a deterministic equivalent for the output of variable RES. Their nominal capacity is reduced with the assumed yearly *resource availability rate* and they are then assumed to produce electricity uniformly over a year. A 1 MW unit with an availability of 25% will thus have a power of 0.25 MW and yield a yearly production of 2,190 MWh [14]. PRIMES justifies this approach by adding extra components to the overall RES costs. This should represent the capital and operational expenses of the Smart Grid technology needed to integrate them [14, p. 26]. PRIMES further assigns a capacity credit to the RES based on which the model determines the necessary BUG to meet the reserve power constraints. It decreases when installed RES capacities increase and varies per country due to different spatial distributions.

[ECF] uses time series for the hourly profiles of the output of variable RES for the entire year. The day-ahead forecast of the RES output is varied through stochastic modelling. Thus several RES output scenarios are taken into account when scheduling generation, storage and use of demand response.

[GRE] relies partly on weather data. 6-hourly wind speed data are linearly interpolated. The hourly output at each node is then calculated using the regional power curves developed in the TradeWind study [19]. The calculation of solar PV output is based on hourly solar radiation data from S@tel-Light [20]. Run-of-the-river hydro is capped at 70% of total capacity with an additional restriction on total energy production to keep overall yearly output compatible with typical full-load hours. The other variable RES (namely geothermal and ocean energy) are considered to produce uniformly at a given percentage of their capacity (respectively 90% and 34%).

It is clear that the representation of RES as uniform production sources makes it impossible to determine whether a given energy system will be able to cope with the variability of these intermittent sources. Although PRIMES focuses more on the economics of the problem, this approach undermines the validity of certain conclusions they formulate, notably when looking at transmission grid expansions. [ECF]'s and [GRE]'s methodologies are better, but [GRE]'s modelling assumes a perfect forecast of variable RES output. For reasons expressed in Section III-A it is better to account for errors in forecasting.

Variable RES can also deliver a number of system services, such as contributing to system security or local voltage controll. Of interest here is the ability of variable RES to deliver balancing energy. The provision of negative balancing power by variable RES, or *smart curtailment*, is relatively straightforward, e.g. the ramping down of a wind turbine. However, providing positive balancing power would require them working below their maximal output level.

PRIMES obviously doesn't need to model the provision of balancing energy services, as they don't consider RES as variable. [ECF] allows negative balancing energy to be provided by these RES. [GRE] also allows *smart curtailment*, but actively tries to minimise it by increasing grid transfer capacities. Its analysis shows that offshore wind is curtailed disproportionally when compared to overall curtailed RES supply (17% vs. 4%). By assigning a cost to RES curtailment, ranging between 3-10 cents/kWh, additional grid reinforcements can be justified, reducing overall curtailment to 1%.

The provision of balancing energy by variable RES might prove crucial when RES dominate the electricity supply. While [ECF] and [GRE] integrate *smart curtailment* in their models, none of the studies consider the provision of positive balancing energy by variable RES as a source of flexibility. Although currently predominantly unprofitable, it could prove to be a valid option, especially in a fully renewable power system.

IV. Modelling demand

The modelling of energy demand in long-term energy system planning models is usually limited to the use of load profiles, possibly adjusted for the assumed energy efficiency policy and penetration rates of heat pumps, electric vehicles (EVs), etc. However, this is where PRIMES excels. Demand is split up into multiple sectors, which are again divided in sub-sectors with different energy usese and technologies. For each sector a representative agent will maximise its benefit, be it utility or profit. In this process every agent decides what equipment to use, how much to invest in energy efficiency and what energy carriers to acquire. This endogenous decision making allows the model to evaluate the uptake of energy efficiency measures. Different scenario assumptions will lead to other penetrations of demand side technologies, resulting in a different overall energy consumption [21].

[ECF] uses hourly load profiles. These have been constructed for each of the 9 regions of its model, based on historical data for the countries in each region. They are then adjusted for the assumed penetration of heat pumps and EVs and the seasonal effects and total demand reduction of energy efficiency measures. These measures are based on the McKinsey Global GHG Abatement Cost Curve.

[GRE] uses hourly national load profiles. Given the higher level of detail of the grid model (224 nodes), these hourly values have to be allocated to the different nodes. [GRE] bases this allocation on population density data from Eurostat, given its high correlation with energy intensive activities. Total energy demand is derived from the work of the *energy [r]evolution* study. It is adjusted downwards for energy efficiency measures and upwards for increased use of heat pumps, hydrogen and EVs. Energy efficiency potential for the different *energy [r]evolution* scenarios were calculated in 2008 by Ecofys and updated in 2012 by the Utrecht University.

A. Demand response

The demand side also has flexibility to offer. The integration of short-term demand response in long-term investment planning models has been shown to dampen system peaks, reducing the need for peak generation investments, and fill valleys in the demand profile, reducing the frequency of oversupply moments [22]. Demand response is often included in energy models as an additional set of constraints to a (stochastic) unit commitment. It is then represented as e.g. an elasticity of the demand or an amount of energy that can be shifted over a certain period of time.

The models reviewed in this paper have differing approaches. Due to its previously discussed simplified modelling approach for the output of variable RES, PRIMES does not explicitly model demand response. In fact all Smart Grid technology, smart metering, grid extensions for connecting RES power plants and grid reinforcements and services needed to facilitate a high penetration of variable RES are modelled implicitly using a cost approach [14].

[ECF] models demand response explicitly in order to assess to what extent it can reduce investments in additional generation capacity and inter-regional transmission. The model can shift 20% of total daily energy demand within a day.

The approach from [GRE] is different, still. Starting from the initial profile demand levels can be altered with a certain percentage of the power. [GRE] estimates this percentage to reach 15% in 2050, given the wide-scale integration of Smart Grids. Additionally the amount of energy that can be shifted in a day is limited, estimated to be 10% at the most without the use of dedicated energy storage, such as EVs.

The obvious disadvantage of these 2 approaches is that it is unclear to what extent they represent the actual potential of demand response. Naturally a simplification of the real processes is necessary to limit computation effort and time, but other more adept approaches exist. [23] develops a method for the construction of aggregated load curves for wet appliances. Instead of shifting energy in the total demand profile, energy is shifted in the appliance-specific load profiles. For each type of wet appliance a maximal amount of energy and period of time over which it can be shifted are determined. [24] applies a similar logic for EVs. An aggregated “energy constraints graph” is developed to represent the specific limitations of the flexibility to be gained during the charging of a fleet of vehicles. [25], the study of a fully renewable Belgian energy system by 2050, considers separately the potential of industrial demand response in the steel sector. These models provide a better representation of the actual processes, a better estimation of the total potential and are still sufficiently simplified.

Moreover, [26], which evaluates the potential of demand response for balancing wind energy, shows that limiting the temporal scope to a single day causes certain benefits of the flexible demand to be lost. If it would be possible to reduce demand significantly for a prolonged period, e.g. a week, certain investments could be (partly) deferred. In a fully renewable system costly measures would be needed to cope with periods of extremely low output. If proven to be more economic than the alternatives, certain types of industry could consider expanding their production capacity to increase their output at times when RES supply is more abundant. At times when both wind and solar energy are scarce, production could be decreased or even stopped. The potential of this kind of flexibility has to this point - to the best of the author’s knowledge - not been investigated within this framework.

Another crucial challenge will be accounting for the uncertainty in scheduling demand. Depending on the governance model that will be used to address demand, just as variable RES output is forecast, flexible demand could be scheduled beforehand. And just as actual RES output can differ from forecast, actual demand might differ from what is planned. The influence of this phenomenon on balancing energy requirements is yet to be evaluated in this setting.

V. Modelling infrastructure

The level of detail of the representation of the power grid differs significantly between the studies. [ECF] has by far the most simplified grid model, with only 9 nodes to represent the European system. Countries are grouped into regions. Every region has a “centre of gravity”, serving as nodes in the grid model. Different types of transmission are defined (see Fig. 1) of which only the transmission between these nodes is modelled explicitly (part A). The cost of such transmission is €1,000 per MW per km, which is also assumed to cover the costs of reinforcing the internal grid (part C). The connection of offshore wind farms to an onshore landing point is modelled implicitly as an additional cost factor in the farms’ CAPEX (part B1). The onshore landing points are connected to a regional node (part B2). The total offshore wind capacity is distributed evenly along the coast line of the region in clusters of up to 5 GW. The transmission cost is only €500 per MW per km as it is assumed that a degree of capacity sharing or refurbishment of existing grid infrastructure could be used. The influence on the distribution grid (part D) is not evaluated, but for a limited impact study for the UK distribution grids.

PRIMES uses one node per country, resulting in 35 nodes and 240 possible connections. The capacity, resistance and reactance of the existing connections are based on ENTSO-E data. The future reinforcements and new connections are assumed exogenous to the model. They are based on project survey information and announcements from the TSOs. A DC linearised power flow is solved to calculate cross-border flows. These simulations are said to show no major congestion issues in the projected transmission grid. Hence no major additional additional interconnection projects are justified.

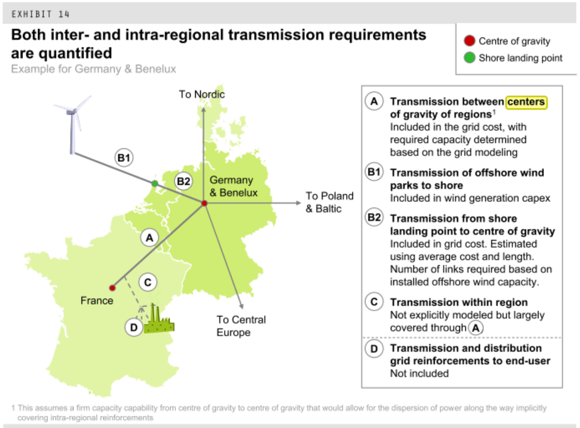

Fig. 1. Different types of transmission defined in [ECF]'s grid model [6]

[GRE]'s main focus are the necessary grid reinforcements required to make an electricity supply with a 97% share of renewables possible. Therefrom it follows logically that their grid model is the most detailed, with 224 nodes. Hourly generation and load levels are determined for each node of the network for the entire year. Subsequently a DC optimum power flow is solved to check feasibility, with line flows restricted to 80% of maximal capacity (to represent N-1 operating conditions). Every time a problem is encountered thermal capacity of the line(s) in question is upgraded. This chronological approach leads to redundant reinforcements. To atone for this the most expensive upgrade is removed at the end of the simulated period. The entire period is reevaluated and if no congestion issues occur the next most expensive upgrade is removed. This process is repeated until no further upgrades can be eliminated. The upgrades of a route are realised with HVAC technology, but limited to up to 3 times the current capacity. Any additional capacity increase is realised with HVDC technology, granted that is at least 1 GW. HVAC reinforcements have a variable cost of €400 per MW per km. HVDC reinforcements have a fixed cost of €150,000 per MW and a variable cost of €1,500 per MW per km.

A. Power exchange

Power exchange offers flexibility by allowing import from and export to other locations. Obviously all four studies allow for this kind of flexibility. However, the potential of several grid technologies (e.g. HVDC technology, phase-shifting transformers) is not investigated or only in a limited way.

Different, more accurate approaches exist to calculate the influence of increasing RES penetration on the transmission grid, some of which also consider the use of controllable lines. Again we can refer to the *dena Grid Study II* [27]. A Power Transfer Distribution Factor (PTDF) model for the inter-regional flows in Germany is constructed. If congestion issues occur additional capacity is realised using controllable HVDC technology. But also this work leaves room for improvement, as part of the motivation for the use of controllable connections is to not impede the validity of the PTDF model. [28] employs yet another methodology, focusing on the Net Transfer Capacities of interconnectors. However, important questions in this context remain unanswered, e.g. exactly what benefit can be achieved from installing controllable lines in comparison to free flow lines.

B. Energy storage

Energy storage could play a major role in increasing the flexibility of the power system. All studies consider pumped storage and other hydro power with a storage reservoir. [EUR] even assumes pumped storage capacity to double between 2010 and 2050. [ECM] also utilises the possibility of the PRIMES model to use hydrogen. The hydrogen, produced via electrolysis, is blended with natural gas with a maximal share of 40%. Other types of storage are not considered in PRIMES.

[ECF] explicitly models storage to asses its influence on investments in additional generation capacity and inter-regional transmission. It does not assume new large scale power storage to be installed as it considers the potential of large hydro in Europe to be almost completely exploited. Concentrated solar power (CSP) is an exception, where units can be equipped with storage with a duration of up to 6 hours. [ECF] also states that no other storage technology exists at this time that can shift energy between seasons in a cost-effective way. Hence open cycle gas turbines have been used to represent the low capital cost and highly flexible BUG source storage would have to be. So i.e. hydro storage and CSP storage are modelled explicitly and BUG consists of only open cycle gas turbines, who's role could in the future be fulfilled in part by actual storage technologies. [ECF] further evaluates an alternative scenario where transmission capacity was substantially reduced from the optimal case. Additional storage capacity would then have to fulfil the balancing role. This leads to 125 GW of supplementary storage power with a capacity of 50 TWh.

[GRE] evaluates a separate scenario in which storage units are located at nodes with high RES capacity and sized to reduce curtailment. Storage power is assumed to be half of the maximal curtailment power (largest unit is 4,895 MW). Capacity is determined so this power can be delivered for 24 hours straight. Storage mainly has to be provided for offshore wind energy, as curtailment of other RES is much rarer in comparison. The influence of storage is found to be very limited. The cause of this result is to be found in the localisation of storage units. [GRE] does not allow these units to be located at offshore nodes. Therefore most storage units can be found at the onshore landing points. As the transfer capacities between offshore wind units and the onshore landing points are lower than the maximal production capacities most of the surplus wind energy is still curtailed and not stored.

Rather than assuming location and size of energy storage systems, it would be more interesting to let the model determine these aspects, as much research already does. [29] tries to quantify to what extent storage can reduce the power imbalances caused by increased RES penetration and how much storage would be needed. [30] attempts to identify the role and value of storage in the UK system. Their model determines not only size and location but also other technical characteristics in order to maximise the added value of storage.

This added value decreases significantly when other technologies, such as demand response or power exchange, are allowed to compete for the delivery of flexibility. Again this shows the importance of simultaneously optimising the roles of these technologies. [31], which evaluates storage and balancing synergies, proves the same point. The requirements for storage peak when average variable RES generation equals demand. Increasing variable RES capacities by a few % dramatically reduces storage capacity needs. Moreover [32] shows that it is crucial to investigate storage governing strategies, as inefficient storage use leads to non-socially optimal behaviour. Less obvious storage techniques should also be evaluated. Instead of storing energy in the form of chemical or kinetic energy, it could be stored in materials or other intermediate goods.

VI. Conclusion

Certain aspects of the power system are not being modelled adequately in those studies that specifically aim at influencing European policy. In the case of the PRIMES model, used for the drafting of the European Commission's own *Energy Roadmap 2050* and EURELECTRIC's *Power Choices*, this leads to scenarios that are a cautious extrapolation of business as usual. The European Climate Foundation's *Roadmap 2050* and Greenpeace's *Battle of the Grids* propose more ambitious scenarios, but do not adequately assess the technical feasibility of certain aspects of the power system's operation or miss potential benefits to be reaped by the simultaneous deployment of different types of flexibility. This in turn leads to e.g. very large grid reinforcements and additional generation capacities.

A number of flexibility options, some of which may seem unlikely today, are not included in these studies. Grid-scale storage, while not fully mature yet, could deliver significant services to the system. More long-term or even seasonal storage, such as could be realised with Power to Gas technology, is overlooked as well. Certain transmission technologies, namely point-to-point or meshed HVDC connections, are already available. Their possible contribution has not yet been evaluated. Demand response could also offer more than what is considered. The ability to lower demand significantly for a prolonged period would again bring benefit to the system, reducing the need for e.g. generation capacity.

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